Novel science for industry?

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Abstract

Measuring novel science as publications which make new combinations of referenced journals and measuring links between science and technology by scientific references in patent applications, we explore the complex relationship between scientific novelty and technology impact. We draw on all the Thomson Reuters Web of Science journal articles published in 2001 and all the patents in PATSTAT version 201310. We find that only a small proportion (about 10%) of all scientific publications are referenced as prior art in subsequent technological inventions, but a small number of scientific papers which score on novelty (about 11%) are significantly more likely to have technological impact, particularly the 1% highly novel scientific papers. The technological impact premium for novel scientific papers is even bigger, when correcting for their initial disadvantage of being less likely published in high impact factor journals. In addition to this superior direct effect, novel science also has a higher indirect technological impact, being more likely to be cited by other scientific papers which have technological impact. Within the set of scientific papers cited at least once by patents, there are no additional significant differences in the speed or the intensity of the technological impact between novel and non-novel scientific prior art, but the technological impact from novel science is significantly broader, covering more diverse technological fields and reaching technology fields previously non-impacted.

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1. Introduction

How well science and industry are interconnected and scientific knowledge can feed into technology development is nowadays recognized as crucial for the innovative performance, growth and competitiveness of nations (Etzkowitz, Webster and Healey 1998, Freeman 1987, Freeman 1991, Lundvall 1992, Nelson 1993). Indicators show an increasing trend in industry science links (e.g., Hicks et al. 2001, Narin, Hamilton and Olivastro 1997). This is partly driven by the strong growth in new science based technologies, such as biotech and nano-tech/new materials. At the same time, corporations –employing more open innovation strategies (Chesbrough 2003) – have been increasingly leveraging public science as an external knowledge source for their technology development, especially in the life sciences (Zucker, Darby and Brewer 1998). From the science side, universities have been called upon to be involved more directly and at larger scale in knowledge transfer (Geuna and Muscio 2009). Some speak of a 'second academic revolution' that took place in the 1990s, adding entrepreneurial objectives as a third mission of the university (Etzkowitz, Webster and Healey 1998) and introducing the notion of 'entrepreneurial universities' (Branscomb, Kodama and Florida 1999, Etzkowitz, Webster and Healey 1998).

While the evidence suggests a growing trend in and a positive effect of industry science links (ISLs) on technology development, there is nevertheless a strong suggestion of an inadequate scale and intensity of such links, especially in Europe. As a consequence, policy measures have been introduced to improve the contribution of universities to national innovation performance (Cohen and Noll 1994, OECD 2003). These policies very often focus on improving the production by universities of patents and spin-offs. However, behind university patenting and spin-offs lies a myriad of informal contacts, personnel mobility, and industry-science networks on a personal or organizational base and open access for industry to scientific publications and conference proceedings. These other forms of transfer of scientific know-how to technology development are more difficult to quantify. Nevertheless they are rated by industry as most important mechanisms to effectively link with science (Hughes and Kitson 2012).

Academic research still has to uncover which mechanisms and processes generate more and more effective ISL and which policy levers work. This research agenda is hampered by lack of standard indicators for ISLs beyond academic patenting. One way of capturing the many links, formal or informal, between science and industry at a large scale is to trace the references in patents to the scientific literature as prior art for their inventions. Despite the ongoing debate about what is actually reflected in scientific NPRs and whether their use for the measurement of science-technology interactions is valid (very much like the discussion in the literature on the wide use of citations in patents to other patents as a measure for the interactions within the technology community), scientific Non-Patent References (sNPRs) are increasingly used in the literature to demonstrate the rising occurrence of ISL over time (Hicks et al. 2001, Narin, Hamilton and Olivastro 1997) and to assess the effects of science-technology interactions on firm innovative performance (Cassiman, Veugelers and Zuniga 2008, Della Malva et al. 2015, Fleming and Sorenson 2004).

Most of the literature using sNPRs takes patents as a starting point and identifies their sNPRs. Much less developed is the literature using the other perspective: taking the publications as a starting point and examining whether they are cited in patents. This latter approach might uncover the differences between technologically relevant science and other publications not cited by patents and thus add to our understanding of the interplay between science and technology.

In this contribution we take the science perspective of sNPRs. We aim to identify which types of science are most likely to be referenced as prior art by patents, with a special interest in scientific novelty. Our interest in novel science resides in its special high gain/high risk characteristics. Scientific breakthroughs often require novel approaches. However, at the same time novel research involves higher risks, is often controversial, and faces resistance by incumbent paradigms. Wang, Stephan & Veugelers (2015) indeed confirm that novel scientific articles, measured by the new combinations in backward references they make, are significantly more likely to become top cited papers. However, they are also more risky, as they display a significantly larger dispersion in their citation performance. These novel papers also encounter difficulties in getting published in journals with higher impact factor, thereby delaying their citation accumulation process. For all these reasons, it is interesting to study the technological impact of novel scientific publications: (i) does their potential for high scientific impact also make them more impactful in technological inventions and particularly open up new areas of technological impact and (ii) does their high risk and delayed scientific impact also affect the likelihood and speed of technological impact?

In this contribution, we draw on all the Thomson Reuters Web of Science (WoS) journal articles published in 2001 and all the patents in PATSTAT version 201310. We find that novel scientific articles are significantly more likely to have technological impact, particularly the highly novel scientific papers. The technological impact premium for novel scientific papers is even bigger, when correcting for their initial disadvantage of being published in low impact factor journals. We do not observe a longer time lag for novel scientific papers to reach technological impact, but the technological impact of novel science is significantly broader and unprecedented, reaching broader technology fields and fields previously non-impacted.

2. Background

2.1. Scientific references in corporate patenting

This contribution will use scientific Non-Patent References (sNPRs), i.e., the references in patents to the scientific literature as prior art for their inventions, to trace the technological impact of scientific articles.

Apart from technical issues regarding the large scale identification of cited scientific sources in patents, there is an ongoing debate about what is actually reflected in scientific NPRs and whether the use of sNPRs as measures of knowledge flows from science to technology is valid, very much like the discussion in the literature on the wide use of citations in patents to other patents as a measure of knowledge flow within the technology community.

In the patent-to-patent citation literature, Jaffe, Trajtenberg and Henderson (1993) argue that "knowledge flows do sometimes leave a paper trail, in the form of citations in patents." Their later survey of inventors verified that the likelihood of actual knowledge spillovers is significantly higher if there is a citation (Jaffe, Trajtenberg and Fogarty 2000), leading to the conclusion that patent citations signal spillovers and can be used to track knowledge flows. Nevertheless, they also note the caveats in the use of patent citations as measures of knowledge spillovers, as not all spillovers are captured in citations, nor all citations represent spillovers. Much of the caveats related to the interpretation of citation-based indicators stem from the fact that a large portion of cited prior art is added by the patent examiner instead of the applicant / inventor and that the norms and procedures of patent referencing vary across patent authorities. For example, Michel and Bettels (2001) note that the USPTO prior-art search is typically a documentary search, whereas the EPO search is a more restrictive patentability search. As such, references in EPO patents might be fewer and more focused than that of USPTO patents (Veugelers et al. 2012).

A limited number of studies have focused on the role and the meaning of scientific references in patent documents. In a small scale case study of nanotechnology patents, Meyer and Persson (1998) find that scientific NPRs may not represent a direct link between the citing patent and the cited article, but the scientific literature plays a more indirect role as a source of relevant background information. Tijssen, Buter and van Leeuwen (2000) also note that NPR-based indicators do not include information about the nature of contribution to the invention or the knowledge transfer involved, and the rationale underlying the selection of citations remains unclear. They assume that citations are primarily meant to indicate significant contributions of scientific research to elements of the invention (Tijssen, Buter and van Leeuwen 2000). However, Callaert, Pellens and Van Looy (2014), based on a small scale interview of inventors, conclude that although scientific references in patents should not be interpreted as direct links between science and technology, most scientific references in patents are considered as relevant by the inventors, at least as background information for the patented invention.

Nagaoka and Yamaouchi (2015) compare sNPRs in patents with survey results of Japanese inventors on whether and which science they rate as essential for their inventions. They find that sNPRs are not only noisy but also incomplete as measure of essential science for inventions. Of the 176 patents with sNPRs, 82% were not judged as "science essential". On the other hand, of the 185 patents for which science was rated as essential, only 37% had sNPRs. Nevertheless, controlling for the propensity to cite NPRs, the revealed NPRs are more likely to predict the existence of essential scientific sources, particularly when the inventor refers to highly cited scientific literature early after its publication.

The validation evidence, although still in its infancy, calls for a careful interpretation of sNPRs. For a scientific publication, being cited by patents does not mean that the cited scientific publication is a direct and essential input for the patented invention but is more likely to indicate that the cited scientific publication serves as relevant background information and source of inspiration for the technological invention. In addition, the differences between inventors and examiner citations, between different patent offices and technology fields, should be taken into account.

2.2. From science to industry

Most of the literature using sNPRs takes patents as a starting point and compared patents with and without sNPRs. Much less developed is the literature using the other perspective: taking the scientific publications as a starting point and examining what types of science are more likely to be cited in patents. This latter approach might uncover the differences between technologically useful science and other publications not cited by patents.

A few studies that have taken the science perspective in industry science links show how concentrated the phenomenon is; only a few publications are referenced by patents. Winnink, Tijssen and van Raan (2013) study the emerging field of intron-related WoS publications and find that only 1% of the identified 15,000 intron-related WoS publications in the period 1986-2001 were cited as sNPRs in 1,284 (1984-2012) intron-related patents. Using a still preliminary search algorithm, Winnink and Tijssen identified about 1.2 million WoS publications (1980-2014) on the basis of all patents available in the 2014 PATSTAT database, meaning about 3.7% of the WoS publications are identified as sNPRs.

The number of sNPRs in patents also depends on the development stage of the technological field. A rapidly developing technological field is generally more dependent on recent scientific knowledge than a mature field. A number of studies focused on and emerging fields, for instance nanotechnology (Finardi 2011, Meyer 2000) and genetic engineering research (Lo 2010).

For understanding the knowledge transfer from science to technology, the speed of transfer is important. This time lag, mostly defined as the time lapse between the publication year of a paper and the application year of the patent citing the focal scientific paper, may differ substantially between fields of technology and is likely to be shorter in emerging fields. Finardi (2011) finds that for nanotechnology the time lag is between 3 and 4 years, while others find time lags of more than 20 years, for instance in the study of the technological impact of library science research (Moed 2012).

2.3. Novel science for industry

In this contribution we take the science perspective of sNPRs. We aim to identify which types of science are most likely to be referenced as prior art by patents, with special interested in science which is novel. Our interest in novel science resides in its specific characteristics.

Research of novel nature, which we can conceptualize following Uzzi et al. (2013) and Wang, Veugelers and Stephan (2015) as research which recombines existing pieces of knowledge components in an unprecedented fashion, has a higher probability of producing scientific breakthroughs than research that draws on existing combinations of knowledge pieces. These novel contributions not only advance the scientific knowledge frontier directly, but also open the door to waves of new follow-on research and thereby futher contributes the scientific advancements indirectly. However, novel research can also face strong resistance from incumbent scientific paradigms and is therefore more likely to encounter impeded or delayed recognition by the relevant community of the importance of the underlying research.

Wang, Veugelers and Stephan (2015) operationalize the combinatorial novelty of scientific research by looking at whether a paper makes new combinations of referenced journals and weighting the number of new combinations by the difficulty of doing so, where difficulty is measured by how many "common friends" the journals have in terms of co-citations. Drawing on all the Thomson Reuters Web of Science journal articles published in 2001, they find that only a handful of scientific papers (about 11%) make novel combinations. These few novel papers have a higher variance in their scientific impact performance, confirming their high risk profile. In addition, they are less likely to be published in journals with high impact factors and have a lower chance of being a top 1% highly cited paper when using a short 3 year window to measure citations. However, these papers have a significantly higher chance to become highly cited papers when using a longer time window (e.g., 13 years). In addition, they are also more likely to have a bigger indirect impact, as indicated by a higher likelihood to be cited by other highly cited papers. All these findings confirm the "high risk/high gain" nature of novel science.

Beyond their impact on pushing forward the scientific frontier, novel scientific articles can also be expected to contribute disproportionally to new technological and industrial possibilities building on the novel ways of combining scientific components. Novel science is thus a prime candidate for serving as a source of inspiration for new technological inventions. Novel science may be particularly relevant for spurring new technological inventions in new fields. This may happen not only directly by the focal novel publication but also indirectly through follow-on scientific contributions building on the original novel publication.

At the same time, it remains unclear whether novel science faces similar impediments in its diffusion in the technological community, like it does in the scientific community, leading to slower speeds of transfers for novel science compared to non-novel science.

In summary, this contribution aims to answer the following research questions:

- Do novel scientific publications have a higher likelihood to be referenced as prior art in patents? Directly? Indirectly through its follow-on scientific publications?
- Does its delayed scientific impact profile, i.e., its initial impeded visibility in science, affects its likelihood to be referenced in patents?

And conditional on being technologically relevant:

- Does novel science take a longer time to be referenced as prior art in patents?
- Does it have a higher intensity of technology impact?
- Does it open up new application domains of certain scientific fields?
- Does it impact a broader scope of technology fields?

3. Data and methodology

The publication dataset we use consists of all research articles in WoS published in 2001 from all subject categories. These are 773,311 journal articles. We exclude papers that have fewer than 2 references and/or no subject category information; articles with more than one subject category (up to six subject categories) are counted multiple times. The final 2001 dataset has 1,056,936 observations.

The patent dataset we use is the ECOOM cleaned EPO, USPTO and WIPO patents of the PATSTAT 201310 version[1].

Non-patent-references in patents are matched to individual publications in WoS, using the algorithm developed by ECOOM (Callaert et al. 2014, Callaert, Grouwels and Van Looy 2012, Magerman, Van Looy and Song 2010). WoS publication are coded as scoring or not on a **sNPR dummy variable** (DsNPR) based on whether they match a non-patent reference in patents filed till 2013. Our major analysis is an analysis of the **likelihood of a scientific paper to be a sNPR**.

Our main characteristic of the scientific publications examined is its novelty. In line with Wang, Veugelers and Stephan (2015), we measure the **novelty of a paper** as the number of new journal pairs in its references weighted by the cosine similarity between the newly-paired journals:

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[1] Reported results are robust for using the non-cleaned version.

$$Novelty = \sum_{J_i - J_j \ pair \ is \ new} (1 - COS_{i,j})$$

As the measure of novelty displays a highly skewed phenomenon of novelty in scientific publications (Wang, Veugelers and Stephan 2015), we use a categorical novelty variable *NOV CAT*: (1) *non-novel*, if a paper has no new journal combinations, (2) *moderately novel*, if a paper makes at least one new combination but has a novelty score lower than the top 1% of its subject category, and (3) *highly novel*, if a paper has a novelty score among the top 1% of its subject category. 89% of all publications are in the first category, 10% in the second category, and by construction 1% in the third category.

As **control variables** we include scientific field fixed effects, as previous literature suggests considerable differences among scientific fields in their relevance for technological developments.

Because of coverage bias and differences in citation behavior across patent offices, we also add three geographic dummies: whether a papers has a (1) US, (2) EPO member state, or (3) Japanese affiliation. EPO only accounts for the 20 members joined before 2001. To further control for the differences in patent offices, we also check robustness of our results using only USPTO or EPO patent data.

In addition, we incorporate a set of variables that are commonly controlled for in analyses ofcitation counts: the number of backward references of the paper, the number of authors and whether it is internationally coauthored.

4. Results

4.1. Descriptive statistics

Before discussing multivariate results, we first present some descriptive statistics. While the descriptive statistics include all subject categories, the econometric analysis excludes those fields which are never cited by any patent.

The descriptive statistics give some first indications that novel papers are more likely to have technological impact, especially the small set of highly novel publications: While on average about 10% of scientific papers serve as sNPR, this probability is 15% for highly novel papers (NOVCAT3), and 12% for moderately novel papers (NOVCAT2).

Novel papers also have a higher probability to have indirect technological impact, through papers citing them: 42% of highly novel papers are cited by papers, which are themselves cited by patents, compared with 29% for non-novel papers.

For those papers that serve as sNPR, the time lag to technological impact is relatively short: their first sNPR takes place about more than 3 years after their publication. There are no extra time lags for novel papers, suggesting that the delayed recognition of novel papers in the scientific community does not take place in the diffusion of novel science in the technological community.

The higher sNPR inclination for novel science only holds in the likelihood of being a reference but not in the intensity of references. There is some limited evidence that their impact is broader, but a strong evidence that they are more likely to have impact in new technological fields of application.

The last column focuses on a small subset of publications which are both highly novel and highly cited by other scientific papers. About 38% of highly cited scientific papers are sNPRs (compared with the average 10%) and about 80% have an indirect impact (compared with 30% on average). Their technological impact seems to come sooner, at higher intensity, being broader and newer.

The prevalence of publications with technological impact is more likely to occur in USPTO than in EPO, and the number of patent citations is also higher in USPTO than in EPO. Nevertheless, the observed effects of scientific novelty on technological impact hold in both patent offices. In the econometrics we will correct for publications from the geographic areas of the major patent offices and also check robustness by analyzing only USPTO or EPO patents. The data also show substantially differences across scientific fields, calling for the inclusion of field dummies in the econometric analysis.[2]

Table D: Descriptive statistics

	ALL	**NOV CAT1**	**NOV CAT2**	**NOV CAT3**	**NOV CAT3 & TOP01% cited**
Number of 2001 papers	1056936	942850	103418	10668	327
% papers cited by patents	9.96%	9.64%	12.31%	15.21%	37.61%
% papers cited by patents (USPTO)	*7.49%*	*7.27%*	*9.13%*	*11.84%*	*34.25%*
% papers cited by patents (EPO)	*4.14%*	*3.98%*	*5.44%*	*6.02%*	*17.43%*
% papers cited by patent-cited papers	30.46%	29.62%	36.91%	42.19%	79.20%

[2] There are remarkable field differences in terms of the rate of being cited by patents. Among the 251 WoS subject categories, fields with the highest rate are: Chemistry, Medicinal (32.45%), Materials Science, Biomaterials (29.66%), Multidisciplinary Sciences (28.31%), Virology (25.21%), and Telecommunications (25.20%). On the other hand, 36 subject categories are not cited in patents at all, these are mostly social sciences and humilities, such as History, Ornithology, Social Work, International Relations, and Language & Linguistics Theory.

% papers cited by patent-cited papers (USPTO)	*23.19%*	*22.57%*	*27.74%*	*33.10%*	*73.70%*
% papers cited by patent-cited papers (EPO)	*19.14%*	*18.49%*	*24.11%*	*28.13%*	*66.67%*
average (first year cited)	2004.4	2004.4	2004.4	2004.5	2003.7
Average # citing patents	3.90	3.90	3.88	4.12	10.31
Average *# citing patents (USPTO)*	*3.45*	*3.45*	*3.41*	*3.62*	*8.89*
Average *# citing patents (EPO)*	*1.70*	*1.71*	*1.63*	*1.73*	*2.56*
% papers being TOP1% patent-cited	8.44%	8.26%	9.44%	10.41%	36.59%
Average # citing IPC4 classes	4.20	4.16	4.37	4.70	9.12
% papers cited by new IPC4	2.85%	2.73%	3.48%	4.56%	11.38%

Data sourced from Thomson Reuters Web of Science Core Collection and EPO Worldwide Patent Statistical Database - October 2013.

4.2. Econometric analysis

4.2.1. On the likelihood that a scientific publication is cited in a patent

The results from the logit regression on the likelihood that a 2001 scientific publication is cited by a patent (till 2013) are displayed in Table 1. The results confirm that novel scientific publications, in particular highly novel publications (NOV CAT3), are indeed more likely to be cited by subsequent patents.

The results also show a positive correlation between impact/visibility in the scientific community and technological impact: papers that have a higher visibility, being published in scientific journals with a higher impact factor, are significantly more likely to be cited in patents.

Controlling for the impact factor of the journal significantly increases the effect of novelty on receiving a patent citation, as the comparison between col 1 and 2 indicates. Although more likely to be published in low impact factor journals (Wang, Veugelers and Stephan 2015), novel scientific papers are still more likely to be cited by patents. Once we correct for the disadvantage of novel paper being published in low impact factor journals, the positive effect of novelty is even more pronounced.

In addition, the more scientific citations a paper receives, reflecting its higher scientific quality, the more likely it is cited in patents. As novel papers are also more likely to be among the highly cited papers (Wang, Veugelers and Stephan 2015), the effect of novelty on technological impact is partly due to its positive association with scientific impact. Once correcting for their higher scientific impact, the positive effect of novelty decreases but remains highly significant and sizeable.

The control variables are all highly significant. Of special interest are the geographic dummies, capturing patent coverage biases and regional biases . US publications are significantly more likely to be cited by patents, in particular by USPTO patents. Internationally co-authored publications are less likely to be cited by patents. This negative effect is even stronger for US publications.

The results are robust when using only USPTO or EPO data, although effects of novelty are somewhat smaller in the latter. In the EPO data, the US differential effects are far less outspoken.

Table 1: Direct technological impact of novel science

	(1) Cited by patents Logit	(2) Cited by patents Logit	(3) Cited by patents Logit	(4) Cited by patents (USPTO) logit	(5) Cited by patents (EPO) logit
NOV CAT2	0.1422***	0.2137***	0.1713***	0.1675***	0.1833***
	(0.0110)	(0.0112)	(0.0114)	(0.0128)	(0.0160)
NOV CAT3	0.2921***	0.4251***	0.3340***	0.3359***	0.2317***
	(0.0298)	(0.0304)	(0.0310)	(0.0340)	(0.0442)
JIF (ln)		0.9808***	0.3310***	0.3334***	0.2497***
		(0.0081)	(0.0092)	(0.0103)	(0.0127)
C14 (ln)			0.6492***	0.6686***	0.6498***
			(0.0041)	(0.0046)	(0.0059)
AUTHORS (ln)	0.4728***	0.3640***	0.2693***	0.2627***	0.3122***
	(0.0065)	(0.0067)	(0.0069)	(0.0077)	(0.0100)
REFS (ln)	0.3273***	0.1268***	-0.1173***	-0.1350***	-0.1121***
	(0.0063)	(0.0066)	(0.0069)	(0.0078)	(0.0103)
US	0.7990***	0.5171***	0.4145***	0.5487***	0.1943***
	(0.0110)	(0.0113)	(0.0115)	(0.0130)	(0.0172)
EP	0.2734***	0.1353***	0.0811***	0.0769***	0.1361***
	(0.0113)	(0.0113)	(0.0116)	(0.0133)	(0.0171)
JP	0.3195***	0.2335***	0.2584***	0.2465***	0.2934***
	(0.0143)	(0.0143)	(0.0146)	(0.0168)	(0.0213)
INT	-0.1248***	-0.1754***	-0.2012***	-0.2087***	-0.1676***
	(0.0217)	(0.0222)	(0.0227)	(0.0258)	(0.0334)
US * INT	-0.2968***	-0.1597***	-0.1142***	-0.1445***	-0.0924**
	(0.0193)	(0.0197)	(0.0201)	(0.0228)	(0.0292)
EP * INT	-0.0493*	-0.0107	0.0079	-0.0283	-0.0285
	(0.0214)	(0.0218)	(0.0224)	(0.0252)	(0.0327)
JP * INT	-0.0995***	-0.0562*	-0.0741*	-0.1122**	-0.0673
	(0.0279)	(0.0284)	(0.0290)	(0.0330)	(0.0409)
N	1048454	1048454	1048454	1048454	1023979
Log lik	-298619	-290780	-275543	-227661	-149598
Chi2	59051***	73954***	88928***	73652***	45253***

Field (subject category) fixed effects incorporated.
Cluster-robust standard errors in parentheses.
*** p<.001, ** p<.01, * p<.05, + p<.10.

Data sourced from Thomson Reuters Web of Science Core Collection and EPO Worldwide Patent Statistical Database - October 2013.

4.2.2. On the likelihood that a scientific publication is cited indirectly by a patent

Table 2 assesses the indirect technological impact of science, i.e., how likely are follow-on papers building on the focal original paper cited by patents. This is particularly relevant for novel science, as they stimulate important follow-on science.

In Table 2, the dependent variable is the likelihood that a paper is cited by a follow-on paper that has technological impact, i.e., cited by patents.

The results are in line with the previous analysis of the direct technological impact of novel science: Novel science, particularly highly novel scientific publications, is more likely to have indirect technological impact. This effect becomes more outspoken once we control for the impact factor of the journal, and this effect remains significant even when we control for the higher scientific impact of the novel paper.

Table 2: Indirect technological impact

	(1) Cited by patent-cited papers logit	**(2) Cited by patent-cited papers logit**	**(3) Cited by patent-cited papers logit**	**(4) Cited by patent-cited papers (USPTO) logit**	**(5) Cited by patent-cited papers (EPO) logit**
NOV CAT2	0.0610***	0.1501***	0.0859***	0.0549***	0.0843***
	(0.0081)	(0.0083)	(0.0092)	(0.0095)	(0.0100)
NOV CAT3	0.1733***	0.3544***	0.2336***	0.1919***	0.2373***
	(0.0234)	(0.0239)	(0.0260)	(0.0263)	(0.0280)
JIF (ln)		1.5675***	0.5913***	0.5787***	0.5310***
		(0.0066)	(0.0077)	(0.0079)	(0.0083)
C14 (ln)			1.1753***	1.1275***	1.1304***
			(0.0034)	(0.0035)	(0.0038)
N	1055650	1055650	1055650	1053850	1052906
Log lik	-526998	-494084	-415874	-382525	-337625
Chi2	158099***	188656***	232546***	200977***	184638***

Included as control variables are the number of authors (ln), the number of references (ln), dummies for US, EP, JP and International co-authorship and their interactions.
Field (subject category) fixed effects incorporated.

Cluster-robust standard errors in parentheses.
*** p<.001, ** p<.01, * p<.05, + p<.10.
Data sourced from Thomson Reuters Web of Science Core Collection and EPO Worldwide Patent Statistical Database - October 2013.

4.2.3. On the time to technology impact

Limiting to the set of publications cited by patents, Table 3 examines the time it takes for the technological impact to materialize. More specifically it looks at the time lag between the year of publication and the year of the first patent citation (OLS analysis).

Unlike the scientific impact which displays a delayed process for novel papers (Wang, Veugelers and Stephan 2015), the technological impact of novel papers does not exhibit any delay. Papers in high impact journals have a significantly shorter time to technological impact, as are papers with more scientific citations. Once correcting for the impact factor of the journal, which is typically lower for novel papers, and the number of scientific citations received, which is typically higher for novel papers (at least in the long run), the time lag for novel papers becomes shorter. However, the effects are small and vary substantially in significance: They are significantly shorter for moderately novel papers among EPO patents, while significantly shorter for highly novel papers among USPTO patents.

Table 3: Time to technological impact

	(1) First year cited OLS	(2) First year cited OLS	(3) First year cited OLS	(4) First year cited (USPTO) OLS	(5) First year cited (EPO) OLS
NOV CAT2	-0.0546+	-0.0835**	-0.0793**	-0.0088	-0.0783*
	(0.0278)	(0.0280)	(0.0277)	(0.0298)	(0.0383)
NOV CAT3	-0.0721	-0.1286+	-0.1203	-0.2307**	-0.1264
	(0.0737)	(0.0739)	(0.0733)	(0.0724)	(0.1131)
JIF (ln)		-0.3722***	-0.3124***	-0.2509***	-0.2744***
		(0.0459)	(0.0499)	(0.0578)	(0.0397)
C14 (ln)			-0.0591***	-0.0630***	0.1081***
			(0.0146)	(0.0139)	(0.0166)
N	105261	105261	105261	79209	43763
R2 within	0.0092	0.0128	0.0132	0.0102	0.0069
F	56***	51***	47***	21***	22***

Included as control variables are the number of authors (ln), the number of references (ln), dummies for US, EP, JP and International co-authorship and their interactions.
Field (subject category) fixed effects incorporated.
Cluster-robust standard errors in parentheses.
*** p<.001, ** p<.01, * p<.05, + p<.10.
Data sourced from Thomson Reuters Web of Science Core Collection and EPO Worldwide Patent Statistical Database - October 2013

4.2.4. On the size of the technology impact

Within the set of publications with technological impact, Table 4 studies the size of their technological impact: How many times are they referenced in patents?

While Table 1 showed that novel science has a higher probability of being cited by patents, novel publications are not more likely, compared with other patent-cited papers, to have a higher number of citing patents or to be among the top 1% papers with the highest number of patent citations in the same publication year and WoS subject category..

A significant correlation is found between the size of scientific impact and the size of technological impact: the larger the number of scientific citations, the larger the number of patent citations. The visibility of the publication, i.e., the impact factor of the journal in which it is published, does not affect significantly the number of received patent citation but does lead to a higher probability of being a top 1% patent-cited paper..

Table 4: Size of the technological impact

	(1) **# citing patents** **Poisson**	(2) **# citing patents** **Poisson**	(3) **Citing patents TOP1%** **logit**
NOV CAT2	0.0064	0.0083	0.0575
	(0.0184)	(0.0185)	(0.0373)
NOV CAT3	0.0305	0.0332	-0.0388
	(0.0506)	(0.0491)	(0.0940)
JIF (ln)		0.0127	0.0866**
		(0.0272)	(0.0321)
C14 (ln)		0.3111***	0.5193***
		(0.0286)	(0.0140)
N	105257	105257	104804
Log lik	-424042	-400633	-25867
Chi2	452***	515***	6378***

Field (subject category) fixed effects incorporated.
Cluster-robust standard errors in parentheses.
*** p<.001, ** p<.01, * p<.05, + p<.10.
Data sourced from Thomson Reuters Web of Science Core Collection and EPO Worldwide Patent Statistical Database - October 2013.

4.2.5. On the nature of the technological impact

In Table 5 we explore the nature of the technological impact. We first look at whether the technological impact of the scientific publications reaches new technological areas, i.e., technological areas that have not yet referenced the scientific field of the focal publication before. The publication which is novel in making new scientific recombinations might also be novel in impacting new technological areas. We therefore expect a positive effect of scientific novelty on reaching new technological areas.

Cols 1&2 confirm that novel scientific publications are more likely to have their technological impact in new technological areas that were not yet reached by their discipline before. While the number of scientific citations also has a positive effect, the journal impact factor has a negative effect.

The last 2 columns of table 5 test the broadness of the technological impact. Cols 3&4 present a Poisson regression analysis on the number of technology areas (IPC4 classes) of impact[3]. Novel scientific publications with technological impact are more likely to have impact in a larger number of technological fields, reflecting their broader impact (col 1). This effect is considerably stronger for highly novel papers and still holds after controlling for the scientific impact (col 2). The significantly positive coefficients on scientific impact and journal impact factor suggest that the more scientific citations a publication receives and/or the higher the impact factor of the journal in which the publication appears, the broader is its technological impact. We also tested interaction effect between novelty and scientific impact or visibility (not reported) and found a significantly positive interaction between NOVCAT3 and top scientific impact, implying that the few publications that combine novelty with big scientific impact have an even broader technological impact than what could have been expected based on their characteristics.

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[3] We include as extra control the intensity of the technological impact, measured as the number of patents citing the paper.

Table 5: Nature of the technological impact

	(1) Cited by new IPC4 logit	(2) Cited by new IPC4 logit	(3) # citing IPC4s Poisson	(4) # citing IPC4s Poisson
NOV CAT2	0.2252***	0.1924**	0.0144+	0.0176*
	(0.0579)	(0.0583)	(0.0075)	(0.0068)
NOV CAT3	0.4465**	0.3681**	0.0834***	0.0862***
	(0.1316)	(0.1315)	(0.0222)	(0.0213)
JIF (ln)		-0.6649***		0.0257**
		(0.0581)		(0.0078)
C14 (ln)		0.2287***		0.0521***
		(0.0201)		(0.0057)
# citing patents (ln)			0.4487***	0.4316***
			(0.0111)	(0.0097)
N	105210	105210	105172	105172
Log lik	-11987	-11877	-218284	-217451
Chi2	3459***	3692***	4992***	4517***

Field (subject category) fixed effects incorporated.
Cluster-robust standard errors in parentheses.
*** p<.001, ** p<.01, * p<.05, + p<.10.
Data sourced from Thomson Reuters Web of Science Core Collection and EPO Worldwide Patent Statistical Database - October 2013.

5. Summary and Conclusions

In this contribution, we take the science perspective of industry science links, examining which types of science are most likely to have technological impact. We are particularly interested in science which is characterized by recombinatorial novelty, as this type of research is more likely to generate breakthroughs.

Wang, Veugelers and Stephan (2015) measure novel science as publications which make new combinations in referenced journals and find that although such publications are less likely to be published in journals with high impact factor or become highly cited in the short run, they have a significantly higher probability to become scientific breakthroughs in the longer run. In addition, they are more likely to stimulate follow-up creativity, as the papers citing novel papers are more likely to be top cited themselves.

Novel science is thus a prime source of inspiration for not only further scientific research but also subsequent technological inventions. This may happen not only directly by the focal novel publication but also indirectly through their follow-on scientific contributions. At the same time, its delayed diffusion in the scientific community may also take place in the technology community.

Measuring, as in Wang, Veugelers and Stephan (2015), novel science as publications which make new combinations in referenced journals and measuring links between science and technology by scientific references in patent applications, we examine the technological impact of novel science. We draw on all the Thomson Reuters Web of Science journal articles published in 2001 and all the patents in PATSTAT version 201310 and match scientific non-patent references using an algorithm developed by (Callaert et al. 2014).

Controlling for scientific field fixed effects and geographic origins, we find that a handful of scientific papers which score on novelty (about 11%) are significantly more likely to have technological impact, particularly the 1% most novel scientific papers. The technological impact premium of novel scientific papers is even bigger when we correct for the disadvantage that novel science is less likely to be published in high impact factor journals. In addition to this superior direct effect, novel science also has a higher indirect technological impact, being more likely to be cited by other scientific papers which have technological impact.

Within the set of papers cited at least once by patents, there are no significant differences in the time lag of technological impact.

While we find no additional significant differences in the scale of the technological impact between novel and non-novel scientific prior art, conditional on having direct technological impact, novel science is significantly more likely to have a broader and unprecedented technological impact, covering more diverse technological fields and reaching technology fields previously not impacted by the scientific fields of the novel publications.

It is widely accepted that novelty is important for science because of its irreplaceable role in advancing the scientific frontier, and this paper provides further evidence that novel science also has greater technological impact. As there is an increasing pressure on science to be economically and socially relevant, our findings suggest that scientific novelty should be encouraged not only for the sake of science itself but also for its greater technological relevance. Therefore, any bias in the current science system against novelty would not only imperil scientific progress but also hinder technological development . Specifically, visibility and impact barriers faced in the scientific community by novel scientific research should be cleared away, and the use of journal impact factors in science evaluations and funding decisions should be treated with care.

However, any discussion of policy implications should await further robustness checks on the results, such as including further characterizations of the novel science that feeds into technology, e.g., its interdisciplinary and breakthrough nature. In addition, the technology that uses novel science needs to be further examined: Who is using novel science as inspiration for the technology development, and which kinds of technological development are spurred by novel science? Furthermore, the use of scientific non-patent references in patents as a measure of the link between the novel scientific idea and the new technology invention needs to be further validated by other quantitative and qualitative information.

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Appendix

Table A1: List of variables

Variable	Description
Cited by patents	Dummy, 1 if cited by patents in PATSTAT version 201310.
Cited by patents (USPTO)	Dummy, 1 if cited by USPTO patents in PATSTAT version 201310.
Cited by patents (EPO)	Dummy, 1 if cited by EPO patents in PATSTAT version 201310.
Cited by patent-cited papers	Dummy, 1 if cited by a subsequent paper which is cited by patents in PATSTAT version 201310.
Cited by patent-cited papers (USPTO)	Dummy, 1 if cited by a subsequent paper which is cited by USPTO patents in PATSTAT version 201310.
Cited by patent-cited papers (EPO)	Dummy, 1 if cited by a subsequent paper which is cited by EPO patents in PATSTAT version 201310.
First year cited	The application year of the first patent citing the focal scientific publication.
First year cited (USPTO)	The application year of the first USPTO patent citing the focal scientific publication.
First year cited (EPO)	The application year of the first EPO patent citing the focal scientific publication.
# citing patents	The number of patents citing the focal scientific paper.
Citing patents TOP 1%	Dummy, 1 if a paper is among the top 1% highly cited paper by patents, in the same publication year and WoS subject category.
# citing IPC4s	The number of technological areas (at the IPC4 level) citing the focal scientific paper.
Cited by new IPC4	Dummy, 1 if a paper is cited in a IPC4 area which has never cited the WoS subject category of the focal paper before.
NOV CAT1	Novelty class dummy: 1 if non-novel, and 0 otherwise.
NOV CAT2	Novelty class dummy: 1 if moderately novel, and 0 otherwise.
NOV CAT3	Novelty class dummy: 1 if highly novel, and 0 otherwise.
C14	The number of scientific citations between 2001 and 2014.
JIF	Impact Factor of the journal where the focal paper is published in.
Authors	The number of authors.
Refs	The number of references.
US	Dummy, 1 if the paper has at least one author from a US institution.
EP	Dummy, 1 if the paper has at least one author from an institution in an EPO member country (20 countries joined before 2001).
JP	Dummy, 1 if the paper has at least one author from a Japanese institution.
International	Dummy, 1 if internationally coauthored.

Table A2: Descriptive statistics and spearman correlations

	Variable	n	Mean	sd	min	max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	Cited by patents	1056936	0.10	0.30	0	1																							
2	… (USPTO)	1056936	0.07	0.26	0	1	.86																						
3	… (EPO)	1056936	0.04	0.20	0	1	.62	.41																					
4	Cited by patent-cited papers	1056936	0.30	0.46	0	1	.35	.30	.23																				
5	… (USPTO)	1056936	0.23	0.42	0	1	.36	.33	.24	.83																			
6	… (EPO)	1056936	0.19	0.39	0	1	.35	.31	.27	.74	.59																		
7	First year cited	105261	2004.4	2.76	1992	2012	.	-.23	-.10	-.06	-.10	-.10																	
8	… (USPTO)	79209	2004.1	2.47	1992	2012	.	.	-.12	-.05	-.06	-.09	.94																
9	… (EPO)	43763	2004.8	2.76	1993	2012	.	-.16	.	-.02	-.05	-.02	.79	.44															
10	# citing patents	105261	3.90	9.90	1	1004	.	.28	.43	.15	.18	.21	-.33	-.31	-.13														
11	Citing patents TOP1%	105261	0.08	0.28	0	1	.	.14	.11	.03	.06	.04	-.17	-.17	-.06	.42													
12	# citing IPC4s	105176	4.20	3.37	1	83	.	.33	.16	.19	.22	.25	-.28	-.19	-.22	.56	.28												
13	Cited by new IPC4	105261	0.03	0.17	0	1	.	.06	-.02	-.04	-.03	-.05	-.05	-.05	-.01	.08	.16	.12											
14	NOV CAT1	1056936	0.89	0.31	0	1	-.03	-.02	-.02	-.05	-.04	-.05	.00	.00	-.01	-.02	-.02	-.03	-.02										
15	NOV CAT2	1056936	0.10	0.30	0	1	.03	.02	.02	.05	.04	.04	.00	.00	.00	.02	.01	.02	.01	-.95									
16	NOV CAT3	1056936	0.01	0.10	0	1	.02	.02	.01	.03	.02	.02	.00	-.01	.01	.01	.01	.01	.01	-.29	-.03								
17	C14	1056936	26.28	72.99	0	30068	.23	.20	.16	.49	.45	.43	-.07	-.07	.00	.19	.11	.24	.00	-.11	.10	.04							
18	JIF	1056936	2.05	2.42	0	33.47	.20	.17	.14	.40	.37	.36	-.12	-.11	-.09	.12	-.02	.23	-.09	-.04	.04	.01	.53						
19	Authors	1056936	4.10	6.18	1	743	.13	.10	.10	.23	.20	.21	-.07	-.06	-.08	.07	-.01	.11	-.06	-.02	.02	.00	.21	.28					
20	Refs	1056936	28.47	18.04	1	631	.06	.05	.05	.17	.16	.17	-.01	-.01	.00	.03	.00	.12	-.03	-.24	.21	.10	.39	.32	.02				
21	US	1056936	0.33	0.47	0	1	.07	.08	.03	.09	.11	.08	-.09	-.08	-.04	.07	.05	.09	.02	-.04	.03	.02	.17	.18	-.03	.16			
22	EP	1056936	0.39	0.49	0	1	-.01	-.02	.01	.02	.01	.02	.04	.03	.03	-.01	-.01	-.02	-.01	-.02	.02	.01	.06	.07	.11	.05	-.38		
23	JP	1056936	0.10	0.30	0	1	.02	.01	.02	.03	.02	.03	.02	.02	-.01	-.02	-.04	-.01	-.02	.04	-.04	-.02	-.04	.02	.14	-.09	-.18	-.22	
24	INT	1056936	0.19	0.39	0	1	.01	.00	.01	.03	.03	.03	.00	.01	-.01	.00	.00	.01	-.01	-.01	.01	.01	.09	.10	.20	.06	.10	.29	.01

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